Virtual Sculpting and Virtual Woodblock Printing as a Tool for Enjoying Creation of 3D Shapes

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Abstract. In this paper, we present an interactive design system based on virtual sculpting to create 3D solid objects, with the stress on the aspect of a tool to enjoy creation or manipulation of 3D shapes. In the virtual sculpting system, a user can form a solid object as if carving a workpiece with chisels. A 3D object generated by the system looks like a real wooden sculpture. If using a board as a workpiece, a user can generate a virtual printing woodblock. A user can synthesize a woodblock print from the virtual woodblock mentioned above, a virtual paper sheet, and a printing brush. In this system, the operations of sculpting and printing are similar to the real ones, and still even children can experience creation of complete computer graphics.

1. Introduction

Recent progress of computer technology enables us to manipulate virtual objects in a 3D space interactively. Interactive generation of arbitrarily shaped objects is one of the most important issues on operations in a virtual space.

As one of the solutions to this problem, we have developed an interactive design system for 3D objects and 2D images (MIZUNO *et al*., 1998a, 1999a). This system consists of sculpting and printing subsystems. A user can experience sculpting and woodblock printing in the virtual space.

For the sculpting subsystem, we implemented the virtual sculpting function: an interactive modeling technique to form a solid object with curved surfaces defined with CSG by carving a virtual workpiece as we do it in the real world. The user performs carving operation directly to a virtual workpiece displayed in the screen. For the printing subsystem, we also propose virtual printing: a method to synthesize a woodblock printing image. From the viewpoint of computer graphics, this is considered as a method to synthesize non-photorealistic images. Virtual items such as a woodblock and a paper sheet are used to synthesize a printing image, and its process is similar to the real one.

Operations of the virtual sculpting and virtual printing are similar to the real ones. It is not necessary to learn special operations and a user who is not familiar to computers like children also can synthesize computer graphics works of virtual objects which looks like a real sculpture or a real woodblock print.

In other researches concerning computer sculpting, GALYEAN and HUGHES (1991) developed a virtual sculpting system using a 3D pointing device and carving an object represented by a 3D voxel array. COQUILLART (1990) and JENG and XIANG (1996) studied virtual sculpting using lattice points representation. NAYLOR (1990) developed an interactive CSG modeling system which performs set operations between a virtual workpiece and tools (chisels). Compared with these methods, both the operation and the shape of an object in our virtual sculpting are similar to the ones in the real sculpting. Among studies of non-photorealistic rendering, SALISBURY *et al*. (1994) developed systems to synthesize images which look like those drawn by writing brushes or pens. SAITO and NAKAJIMA (1995) developed methods to transform an original image to the one similar to a painting. SOUSA and BUCHANAN (1999) developed methods to render a 3D model by the way like a painting. In addition to various methods which have been developed, synthesis of woodcut printing presented here has become another efficient method to generate non-photorealistic images.

2. Overview of the Interactive Design System

Our interactive design system consists of two subsystems for virtual sculpting and virtual printing (Fig. 1) (MIZUNO *et al.*, 1998a, 1999a). In the sculpting subsystem, the user can form a 3D solid object interactively by carving a virtual workpiece with virtual chisels. A user operates a virtual chisel whose tip is defined with an ellipsoid, a cube or a cylinder, and can remove or attach their own shape, from or to the virtual workpiece rendered with shadowing. By performing this carving operation repeatedly, the user can form arbitrarily shaped solid objects. The shape of a carved solid object is described with a CSG expression by surfaces as the primitives. In the virtual printing subsystem, a user can synthesize a woodblock print from a woodblock, a paper sheet, and a printing brush in a virtual space. A virtual woodblock is generated by virtual sculpting. A gray value at each point on a virtual paper sheet is decided based on a distance between a paper sheet and a woodblock.

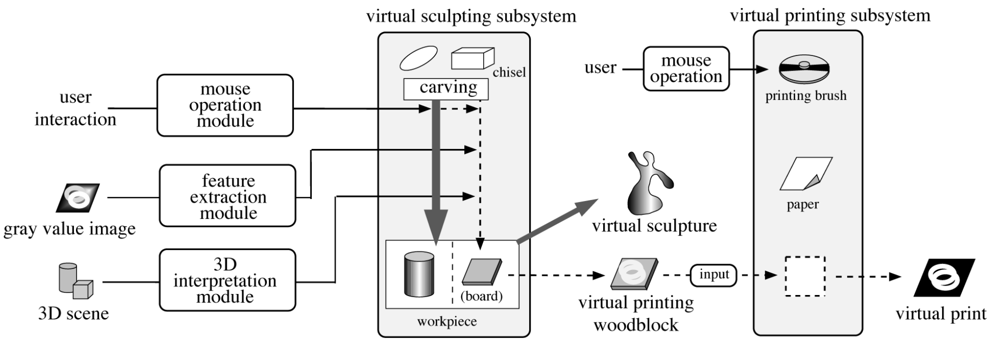


Fig. 1. A system for virtual sculpting and woodblock printing.

A woodblock print images is synthesized by operation of a virtual printing brush as many times as a user want. Thus, it is a simulation of the real woodblock printing process, and the images by our virtual printing is expected to be similar to the real woodcut prints.

3. Virtual Sculpting

3.1. Generating a solid object

In the virtual sculpting subsystem, an original workpiece and several virtual chisels are prepared in a virtual space. Each virtual chisel is defined by an ellipsoid, a cube, a cylinder or combination of them. As carving operations, the user can remove or attach pieces of virtual chisels from or to the workpiece. Removing/attaching is the operation which subtracts/adds the pieces. By performing these operations repeatedly, the user can form a complex solid object.

The original workpiece is a curved surface polyhedron that is a simple shape defined with a CSG expression. An ellipsoid and a cylinder are used like a round chisel (gouge). We believe that a real carved surface created by a gouge is similar to a portion of an ellipsoidal and a cylindrical surface. We add a cube as a flat chisel, and a user can use it for rough carving or new expression of a virtual sculpture.

The shape of a carved solid object is expressed by a carving record of the user's operations, or a logical formula of the primitives constructing the object.

3.2. User interface

We aim at the operation that is simple and similar to the real sculpting. The user operates a virtual chisel with a mouse device and carves a virtual workpiece directory.

Several virtual chisels with different width, depth, and shape are prepared beforehand by the system, and user selects one from them. And user selects operation type from removing and attaching. Next, the mouse cursor is moved on a workpiece displayed in the drawing screen, and when the mouse cursor is dragged and the button is released, a point on the surface of the workpiece in the virtual space is determined, and the center point, length and the direction of the chisel are determined by the length and the direction of dragging, and the normal vector of the surface of the workpiece (Fig. 2). The workpiece is deformed by the chisel placed in the virtual space at the moment. The user can carve the solid object interactively as if carving it in the real world. Combining cubes and cylinders, the user can carve the virtual workpiece on a curved line like sawing (Fig. 3). Figure 4 shows examples of the carving variations.

3.3. CSG

The CSG (Constructive Solid Geometry) method describes a solid object with a set operation of primitives. We adopt the CSG because it is a method of solid modeling that has few restrictions on deformation by carving and it is suitable for virtual sculpting. And the shapes of generated objects have no finite resolution such as voxel expression. In our system, quadric surfaces are used as CSG primitives (OKADA *et al.*, 1997). An ellipsoidal chisel is defined with one quadric surface, and a cubic surface of a flat chisel is defined with three quadric surfaces which are actually pairs of parallel infinite planes. A cylindrical chisel is defined with a infinite cylinder and a pair of infinite parallel planes.

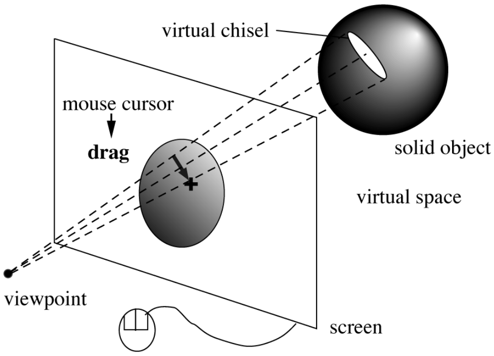


Fig. 2. Placing a virtual chisel.

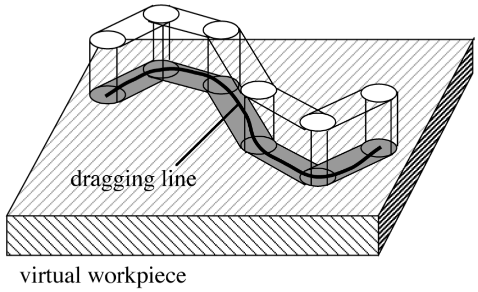
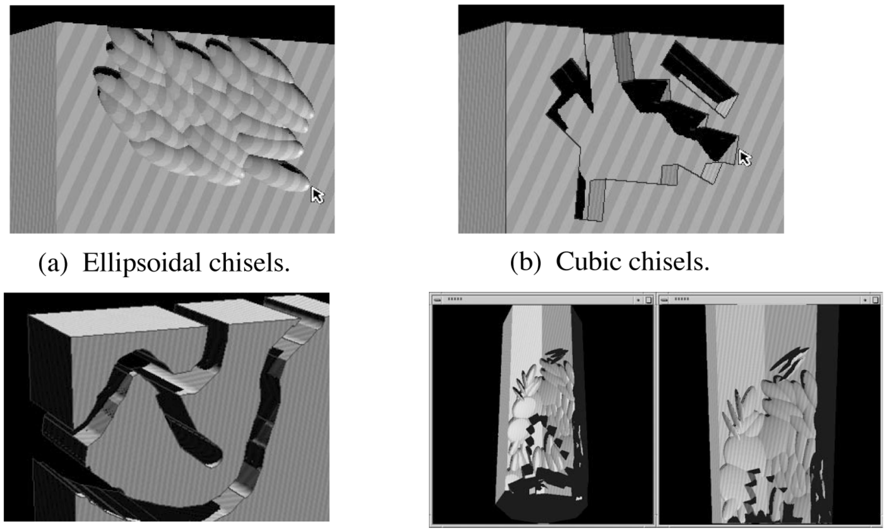


Fig. 3. Carving on a curved line.



(a) Ellipsoidal chisels.

(b) Cubic chisels.

(c) Sawing (cylinders and cubes).

(d) Drawing screens with each viewpoint.

Fig. 4. Carving variations.

3.4. List of intersecting points

It is necessary to deform the surface of the workpiece in the drawing screens after each carving operation. To do it in real time, a list of intersecting points along each viewing line on the screen is generated (Fig. 5). This list is composed of all intersecting points between the workpiece and each viewing line arranged according to the distance from the viewpoint. Lists for an original workpiece are generated first. Redrawing the object after applying a carving operation is performed by renewing lists and using the head of each renewed list (Fig. 5).

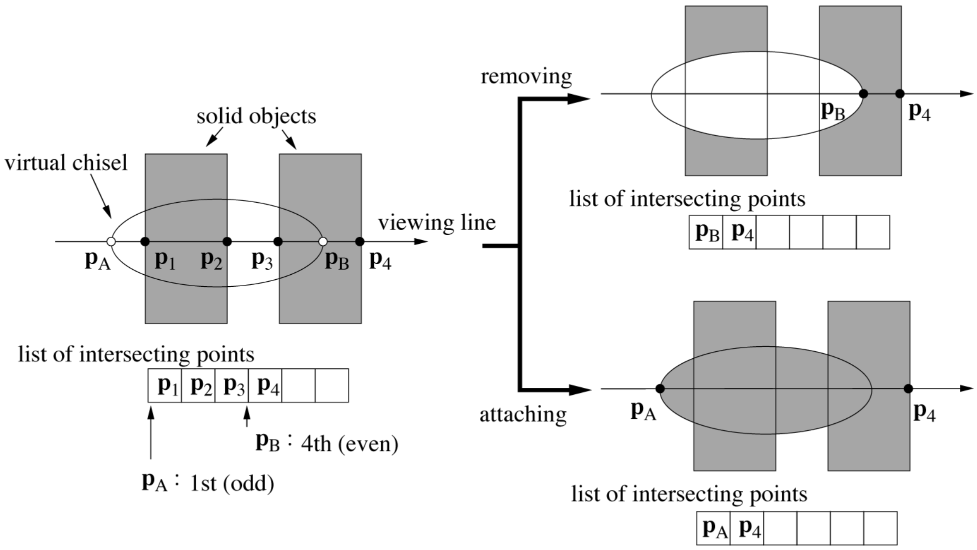


Fig. 5. A list of intersecting points and its renewing.

Shadowing a virtual workpiece makes the rendered image more realistic and it is helpful to recognize its solid shape in carving. We newly add a faculty for shadowing to the system by projecting the workpiece from a source of light (ATHERTON *et al.*, 1978).

In our system, it takes about less than 0.3 sec to deform the surface for one carving operation on condition that the resolution is 512×512 and a workpiece is rendered with shadowing. This computation time is fast enough for interactive virtual sculpting. The lists is also used to generate an image of the carved object seen from another viewpoint by renewing the lists according to the carving record (the succession of “removing” or “attaching”).

4. Virtual Printing

4.1. Fundamental principle

A virtual woodblock printing is synthesized with virtual items consisting of “a printing woodblock”, “a paper sheet”, and “a printing brush” in a virtual 3D space (Fig. 6). It is similar to the one in the real world. In the real woodblock printing, the woodblock prints the paper sheet as gray only at each point where the block touches the paper, and the gray value is decided based on the pressure of the paper to the block. Larger pressure values appear at the part of the sheet where the block bulges or the sheet is rubbed strongly. In the virtual printing, the gray value of each point on the virtual paper sheet is decided by the distance from the sheet to the virtual woodblock at each point, and the gray value increases with decreasing the distance. A virtual printing brush is used to change the distance from the virtual paper sheet to the virtual woodblock locally. The distance is decreased little by little by operating the virtual printing brush, and a virtual print is synthesized interactively.

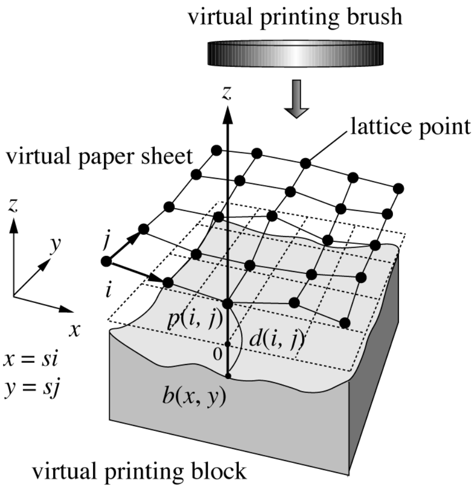


Fig. 6. Virtual items for printing.

4.2. Virtual items for woodblock printing

A virtual woodblock to synthesize a print is generated in the virtual sculpting subsystem mentioned above. It is generated from a virtual wood board as an original workpiece, and placed in virtual space in parallel with a plane defined with x and y axes.

A virtual paper sheet is expressed as a 2D lattice (i, j) and placed in parallel with the x-y plane in the virtual space at first. The lattice points can move only in the direction of the z axis.

A printing brush, called "baren" in Japanese, is used to decrease the distance between the paper sheet and the woodblock $d(i, j)$ at each lattice point. A virtual printing brush is defined with a circular plank and placed on the virtual printing block in parallel with it. When the virtual printing brush is operated, every lattice point under the printing brush which has a z value larger than the z value of the printing brush is considered to be pushed by the printing brush, and is moved to the base of the printing brush as far as the lattice point does not cave in the woodblock. This operation is performed whenever the virtual printing brush is moved, and as the user operates it repeatedly, the virtual paper sheet approaches the surface of the virtual woodblock gradually.

4.3. Synthesis of a woodcut print

The virtual printing brush is operated with a mouse device, and by using it, we can simulate the action of rubbing a paper sheet. The woodblock prints are synthesized one after another every time a user operates the virtual printing brush.

A gray value $f(i, j)$ at each lattice point of the virtual paper sheet is computed with the following expressions:

$$f(i, j) = \begin{cases} 0 : \text{if } d(i, j) > t_d, \\ a(t_d - d(i, j)) : \text{otherwise}, \end{cases} \qquad (a,\ t_d\text{: constant } (> 0)).$$

With this expression, the removed areas of the printing block print the sheet with white and the others with black. In virtual printing, the grain of wood is simulated by giving grooves to the virtual printing block with gray value image of actual grain.

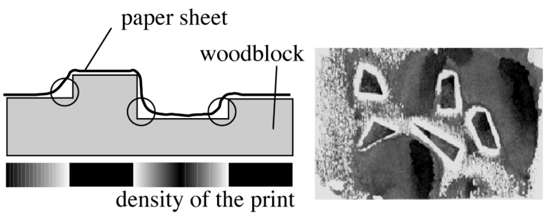
In the real woodblock printing, gray values at the surface step of the woodblock become lower (Fig. 7(a)). It is important for the synthesis of a realistic woodblock print to simulate this phenomenon. This effect can be realized by setting limits in the amount of shift of the virtual paper sheet based upon the convex hull of the woodblock (MILLER, 1994). Figure 7(b) shows the basic idea.

5. Experiment and Discussion

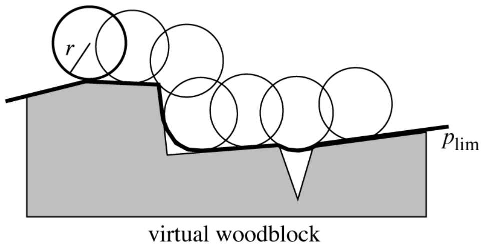
5.1. Examples of applications

We implemented the above mentioned design system on a work station and tested the performance. Figure 8 shows the process of generating a virtual sculpture. An original workpiece (a cube) is prepared in virtual space (a), rough carving by the flat chisel is executed (b), and finishing touches by the round chisel (gouge) are given (c). The whole of the process is similar to sculpting in the real world, and the generated solid object looks like a real wooden sculpture. Figure 9 shows examples of virtual sculptures and prints generated by this virtual sculpting and printing.

We also tested the system by opening it to primary and middle school pupils. First we explained the use of the system for about one hour, and had them to play with the system freely. Figure 10 shows examples of the work generated by children of about 10 years old. All children got experienced in operation of this system immediately and enjoyed designing. They completed many works in a little less than 30 minutes. It is shown that the user of this system can operate without special knowledge and generate solid objects with ease.



(a) The actual printing.



(b) Linits in amount of shift of the paper sheet.

Fig. 7. Effect at the step portions of woodblock.

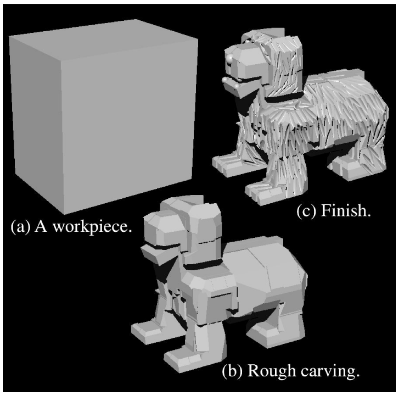
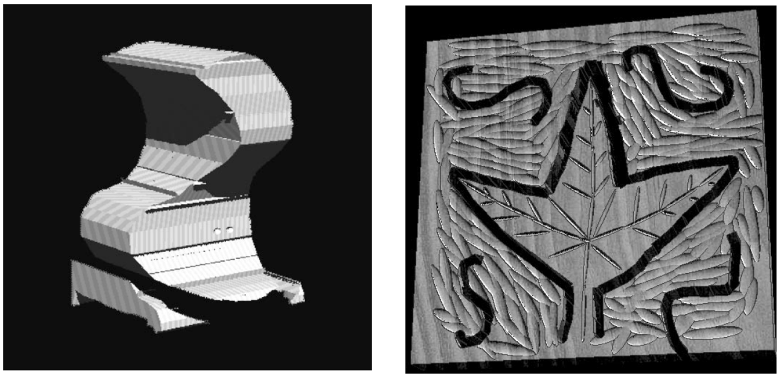


Fig. 8. Process of generating a virtual sculpture.



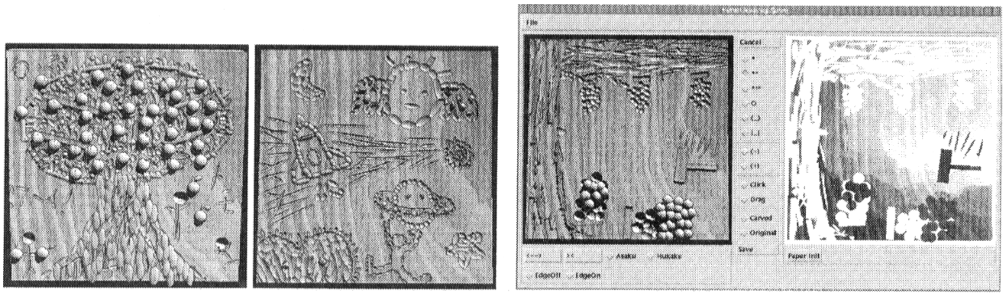
(a) Object. (b) Leaf.

Fig. 9. Examples of virtual sculptures.

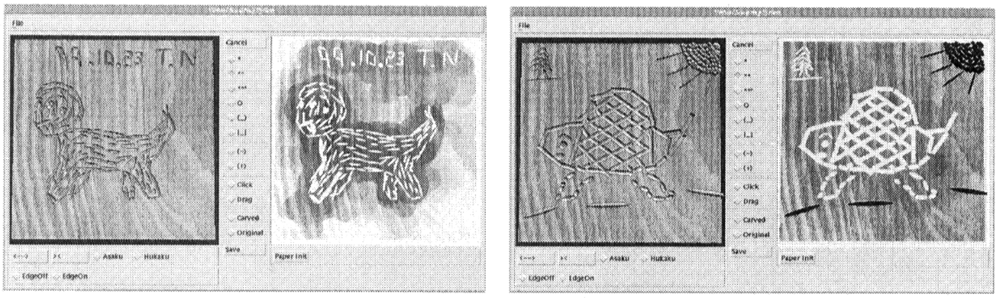
5.2. Discussion

One important objective of this study is to realize a software tool for enjoying creation of 3D form freely. From this viewpoint, we first developed the virtual sculpting system. The virtual woodblock printing was developed by using the sculpting system to generate a woodblock in the virtual space, and then adding the virtual printing system newly developed.

The long-term goal of this study is to develope a new tool for manipulating 3D form freely. As the first step to access to this problem, we started by simulating a methodology existing in the real world. The first study in our laboratory along this direction was "ORIGAMI" on computer (TORIWAKI and MIYAZAKI, 1994). This paper includes the second (sculpting) and the third (woodblock printing) experiment. One of important advantage in simulating real world techniques is the user's familiarity to the methods and



(a) Relief 1. (b) Relief 2. (c) Woodblock and its print 1.



(d) Woodblock and its print 2. (e) Woodblock and its print 3.

Fig. 10. Works generated by children.

functions realized in computer systems*. For example, the woodblock printing is a traditional style of old Japanese painting, and also very popular even now among elementary school children. For most of elementary schools and middle schools, woodblock printing (“HANGA”) is presented in the course of art and painting. This is one reason that children who saw this system for the first time could generate good pieces work only after one hour of lecture.

However, the simulation of real world sculpting and real woodblock printing, or “the reality” in the strict scene is not our final goal. In fact, our present system is critically different from the real sculpting and the woodblock printing in that the virtual sculpting and the woodblock printing system in computer do not have any physical properties of the real material such as stone, marble and wood. The virtual material in our system does not have elasticity nor plasticity. Similarly, the virtual chisels does not have any physical properties. Users never feel the reactive force and physical weight from the material they are manipulating. Some of those problems may be improved by introducing the modification of deformation process in computer considering the properties of the virtual material. This

* Various systems for generating 3D forms by computer have been developed for the use of artists or professionals. For example, a rule-based system by LATHAM (1989), and form generation by the growth model by KAWAGUCHI (1994) are noted. They do not have the counterpart in the existing form generation methodology.

is the interesting problem to be studied in the future. Now the type of chisels available in our system is limited, but the improvement in this point is not difficult.

On the other hand, the virtual sculpting and the virtual woodblock printing have their own advantages over the real ones as follows.

(1) Not only removing the part of material but attaching pieces of material is possible without any difficulty.

(2) Users do not need worry about the failure in any of cutting workpiece, printing and any other steps of the procedure because doing the whole or part of the process over again is very easy.

(3) Arbitrary form which may not be realizable in the real world can be produced such as a complicated shape of cavity inside the piece and extremely thin three dimensional line figures.

(4) Anyone who cannot manipulate a real chisel including quite unexperienced children and a handicapped person can enjoy the creation of 3D form.

(5) Enjoying only specific part of the procedure is possible. For example, a user may have interest in only sculpting the woodpiece. Another user may want to do only the designing of color arrangement or to test the variation of the way of printing in the woodblock printing, but they may not intend to perform sculpting themselves. Such user can select only the process they want to experience.

Considering all these characteristics, we consider the system described here is a new tool of design or 3D form generation rather than a simple simulation of real sculpting and woodblock printing.

6. Conclusion

In this paper we implemented an interactive design system based on virtual sculpting and virtual printing on a workstation. In the virtual sculpting, a user can form realistic virtual wooden sculpture by applying carving operations to the virtual workpiece rendered with shadowing as if carving in the real world. It is realized by introducing a virtual chisel defined by an ellipsoid, a cube and cylinder, and the lists of intersecting points. In the virtual printing, a user can synthesize an image like a woodblock print from a virtual woodblock generated by the virtual sculpting. Using a virtual “paper sheet”, “woodblock”, and “printing brush”, we can synthesize a realistic woodblock print with a procedure similar to the real woodcut printing.

We had children use our design system and generate virtual object actually. This experiment showed that the system presented here was usable for anyone without special knowledge about computer and graphics to generate 3D solid objects, and this system made synthesizing computer graphics image more familiar to many people.

We are continuing improvement and extension of the system in a few directions. Multicolor printing, and automated woodblock generation from a given picture or from a given 3D scene were already developed (MIZUNO *et al.*, 1998b, 1999b). Use of material as a workpiece other than wood such as metal, glass and crystal is now being studied. We are going to develop more user friendly and realistic interface with employing force feedback devices. Furthermore the possibility to bring virtual works by our system to the real world by utilizing machining tool is also considered.

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